Significance of Semiannual Waves in the Mesospheric Zonal Wind and Evidence of Influence by the Geomagnetic Field

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The recently described polar semiannual oscillations in zonal wind can explain midwinter weakening of the polar winter vortex and the relatively short stratospheric and mesospheric summer easterlies. This explanation implies that stratospheric sudden warmings may be caused or affected by the polar semiannual oscillation. Two potential physical mechanisms (not mutually exclusive) for the oscillation are presented: planetary wave action and changes in the radiation field. Radiation absorption changes are suggested to result from changes in ozone concentration during magnetic storms. Contours of amplitude of both the polar and tropical semiannual wind oscillations are more nearly congruent with geomagnetic than with geographic latitude.

Two new distinct polar centers of the semiannual oscillation of mesospheric zonal wind have recently been identified [*Groves*, 1972; *Belmont et al.*, 1974]. The well-known tropical center (Figure 1) is centered near the geographic equator at about 45 km, a northern center is near 60°N at about 65 km, and a southern one is near 70°S at 60 km. Original attempts to explain the tropical oscillation attributed it to the semiannual variation of insolation at the equator due to changes of the solar zenith angle [*Webb*, 1966]. This mechanism, however, would inherently demand equatorial symmetry, which in Figure 1 is not found to exist [*Belmont and Dartt*, 1973]. Furthermore, energy and momentum considerations have shown that some other process is forcing this oscillation. *Meyer*'s [1970] study of the dynamics of the tropical semiannual oscillation shows that an eddy momentum flux by tidal motions could furnish the necessary energy. However, because of the rapid variations of tidal phase with altitude he concludes that other mechanisms also probably contribute in driving the tropical wave. This conclusion will be considered later. The newly described polar center of the semiannual oscillation is of great interest for several reasons. It can help explain the long-observed weakening of the intense winter polar westerlies as seen on time sections [*Belmont and Dartt*, 1970]. This decrease in winter westerlies was attributed by *Webb* [1966] to the intrusion of the summer hemisphere easterlies into the winter hemisphere, i.e., to the semiannual wave in the tropics, although no direct influence could be measured. The existence of the separate polar semiannual oscillation, however, can now directly explain this phenomenon, as can be seen in Figure 2, where the annual and semiannual are superposed on the long-term mean to produce a resultant yearly cycle. Amplitudes and phases used in the figure are for 55°N at 60 km from *Belmont et al.* [1974]. The semiannual wave is likely to be related to the winter polar sudden warmings.

The polar semiannual oscillation can also explain the relatively short duration of the stratospheric summer easterlies, as can be seen in Figure 2. This short-summer effect varies with location and altitude, being a function of the relative amplitude and phase lag between annual and semiannual waves.

No explanation has yet been offered for the polar wave, but two possibilities can be proposed: upward transport of wave energy and downward transport of energetic particles resulting in changes in radiative properties. They both have shortcomings within the framework of present theory and observational evidence, but the following suggestions may stimulate further investigation.

One possible mechanism for the polar semiannual oscillation, and perhaps a contributing factor in tropical regions, is the interaction of vertically propagating planetary waves with the mean flow. The equinoctial nature of the reversal of the stratospheric zonal wind, resulting in the weak vertical shears required for planetary wave propagation [see *Clark*, 1972, for a review], provides favorable conditions. Could it be that planetary wave absorption is also responsible for the small secondary maximum found near 30°N (Figure 1)? As regards the polar maximum, however, some aspects of this hypothesis remain in doubt. The observed polar oscillation has a distinct center near 65 km at 55°N: if planetary waves were responsible should the center not be distributed evenly over a broad band of latitude and altitude since the wind reversals occur throughout the stratosphere? Also, *Dickinson* [1969] could find no direct evidence of enhanced planetary wave flux at the equinoxes and has explained this finding as resulting from damping of the waves by Newtonian cooling. Thus the planetary wave hypothesis needs further refinement so that it can explain these apparent discrepancies with observations if it is to be accepted as the source of the polar wave.

The location of the polar wave in the auroral zone and its altitude just below auroral heights is intriguing, and a possible relation should be examined. In Figure 3 the amplitude of the semiannual wave at 50 km is plotted in geomagnetic Mercator coordinates; Figure 4 shows the same data in geographic Mercator coordinates. Note that the north-south variations of the contours are smaller in geomagnetic rather than geographic coordinates. Figures 5 and 6 present the same data in geomagnetic and geographic polar coordinates, respectively. Once again, note the greater symmetry of the contours in geomagnetic coordinates. This suggests that the semiannual oscillation is coupled with the geomagnetic, rather than geographic, coordinate system. Rocket stations depicted by

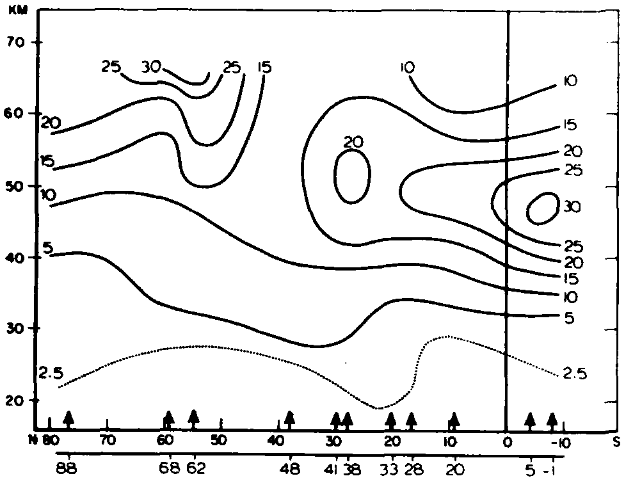

Fig. 1. Amplitude of the semiannual wave in zonal wind (meters per second) for stations near 80°W. Arrows indicate rocket stations. Bottom scale is geomagnetic latitude.

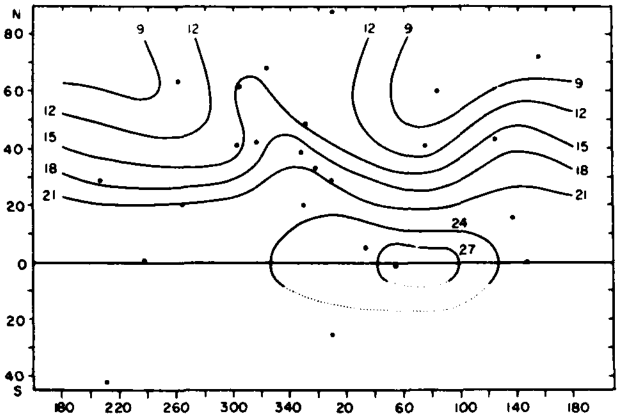

Fig. 3. Amplitude (in meters per second) of the semiannual wave at 50 km in geomagnetic Mercator coordinates.

dots on the figures and the corresponding amplitude of the semiannual wave at 50 km are listed by *Belmont et al.* [1974] except for Thumba (9°N, 77°E), Arenosillo (37°N, 7°E), Ryori (39°N, 141°E), Sonmiani (25°N, 67°E), and West Geirinish (57°N, 7°W) that have been added.

Since the phase of semiannual zonal wind oscillation is equinoctial, as is the phase of geomagnetic variations [*Chapman and Bartels*, 1940], and since the magnetic storm semiannual variation is due to extraterrestrial causes [*Russell and McPherron*, 1973] and thus not to the atmosphere, the coincidences require an explanation. Direct magnetic field control of the circulation at mesospheric altitudes can be rejected from energy considerations. However, the magnetic field might still indirectly influence the mesospheric circulation. Energy arguments against solar-terrestrial effects do not take into account that changes in species concentration from particle precipitation could result in changes in radiative properties of the layer and thus to changes in thermal gradients.

A coupling of the magnetosphere and thermosphere with the mesosphere might occur through influence upon the radiation field as follows: The semiannual component in the occurrence of magnetic storms leads to semiannual auroral activity. Through particle precipitation associated with this activity, energy is dissipated in the lower thermosphere down to the mesopause. But, more importantly, the particle precipitation may lead at these levels to production of O through electron impact dissociation of O_2, which in turn increases ozone through three-body recombination [*Maeda*, 1968; *Maeda and Aiken*, 1968]. This leads to a semiannual control of ozone and through its absorption of UV to a semiannual oscillation in the temperature and wind fields. Although enough measurements have been made to preliminarily identify an annual variation in ozone at these levels [*Evans and Llewellyn*, 1972], observational verification of a semiannual component in ozone is not yet available. If geomagnetic activity is indeed the cause of the polar semiannual wave, this behavior implies that it may thus influence the development of sudden warmings that are disturbances of the thermal field and that progress downward from about 50 km.

The tropical wind oscillation appears located closer to the geomagnetic than the geographic equator (Figures 1, 3, and 4). Also, note that the presently known extreme maximum of the tropical oscillation is centered near the anomalously weak magnetic field in the South Atlantic and Brazil. At tropical latitudes the most particle precipitation occurs in the region of relatively weakest magnetic field [*Reagan and Imhof*, 1970;

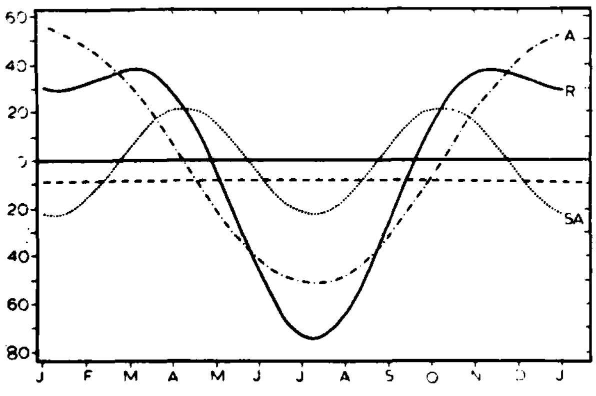

Fig. 2. Yearly wind cycle (R) (in meters per second) resulting from addition of annual (A) and semiannual (SA) waves at 60 km at Primrose Lake (55°N).

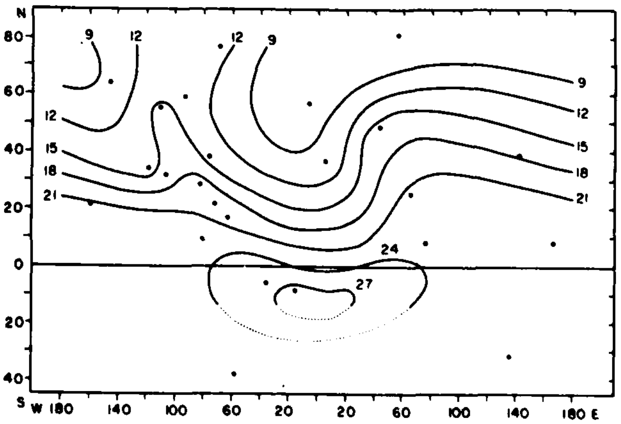

Fig. 4. Amplitude (in meters per second) of the semiannual wave at 50 km in geographic Mercator coordinates.

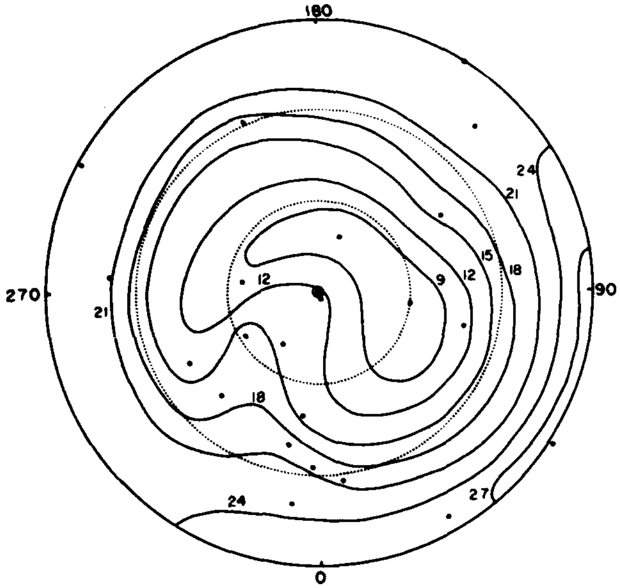

Fig. 5. Amplitude (in meters per second) of the semiannual wave at 50 km in geomagnetic polar coordinates. The dotted latitudes are 30° and 60°.

Trivedi et al., 1973]. The phases of both the tropical and the polar semiannual oscillations are equinoctial [*Belmont and Dartt*, 1973], and although they are separated by more than a scale height in altitude, they could very well be influenced by the same mechanism because of their similarity of phase. Could it be that the semiannual component in magnetic storm activity influences the tropical wind field so as to shift the tropical semiannual wind oscillation toward the geomagnetic equator? This could then help resolve the dynamic modeling problem encountered by *Meyer* [1970].

In summary the following points are noted:

1. The polar semiannual wind wave can help explain the decrease in strength of the midwinter stratospheric and mesospheric westerlies and the shorter summer season in the stratosphere.

2. The phases of both the polar and the tropical semiannual wind oscillatio.. are very similar to the phase of the semiannual component in magnetic storm activity, and the amplitude, at a given level, of the semiannual wind oscillation appears more symmetric in geomagnetic rather than geographic coordinates.

3. Explanation of the polar semiannual center in terms of planetary wave absorption is uncertain by present observational and theoretical evidence. However, planetary wave absorption may be a contributing factor to the double-lobed appearance of the tropical center.

4. It is also suggested that the polar semiannual wind centers may be caused by the UV heating of the mesospheric ozone, which is contributed semiannually by particle precipitation during magnetic storms. The same process may influence the random occurrence of sudden warmings.

5. The tropical semiannual wind center may be influenced enough by similar processes to account for its apparent symmetry in the geomagnetic coordinate system.

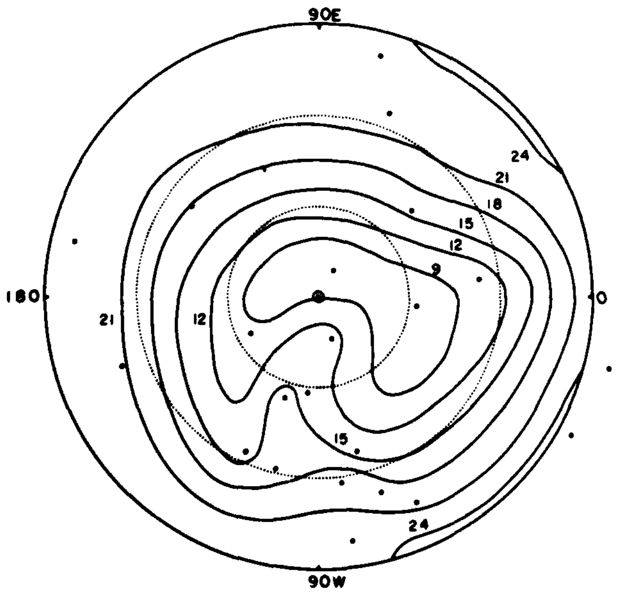

Fig. 6. Amplitude (in meters per second) of the semiannual wave at 50 km in geographic polar coordinates. The dotted latitudes are 30° and 60°.

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